

WHAT IS CLAIMED IS:

1. An interior permanent magnet synchronous motor comprising:
 - a stator including a stator core provided with a plurality of magnetic pole sections having windings of at least one phase wound thereon;
 - a rotor having p pole pairs (p : a positive integer of 1 or more);
 - said rotor including a shaft and a rotor core fixed on said shaft;
 - said rotor core having $2p$ permanent magnets incorporated therein in a manner to be spaced from each other at intervals in a peripheral direction thereof;
 - said $2p$ permanent magnets constituting $2p$ permanent magnet magnetic pole sections formed on an outer periphery of said rotor core;
 - said rotor being formed with $2p$ magnetic salient pole sections so as to interpose said permanent magnet magnetic pole section therebetween;
 - said $2p$ magnetic salient pole sections consisting of a first and a second groups of magnetic salient pole sections, said first group consisting of p magnetic salient pole sections arranged so as to be spaced at equal intervals in the peripheral direction while each of the magnetic salient pole sections of a second group is interposed between two adjacent magnetic salient pole sections and said second group consisting of p magnetic salient pole sections arranged so as to be spaced at equal intervals in the peripheral direction while each of magnetic salient pole sections of the first group is interposed between two adjacent magnetic salient pole sections;
 - wherein an open angle $\alpha 1$ of said p magnetic salient pole sections of said first group is set smaller than an open angle $\alpha 2$ of said p magnetic salient pole sections of said second group;

said open angles α_1 and α_2 are determined to satisfy the following expressions:

$$\alpha_2 - \alpha_1 \approx 2\beta - (2n-1)\tau_s$$

wherein n is a natural number, β is an angle between two salient pole section virtual center lines CL1, CL2 which extend from the center of said shaft through the center of said two adjacent magnetic salient pole sections, and τ_s is the slot pitch of said stator core.

2. The interior permanent magnet synchronous motor as defined in claim 1, wherein curvature radius R_1 of said p magnetic salient pole sections of the first group is smaller than curvature radius R_2 of said p magnetic salient pole sections of the second group.

3. The interior permanent magnet synchronous motor as defined in claim 1, wherein the shapes of said $2p$ permanent magnet magnetic pole sections and said $2p$ magnetic salient pole sections are determined so that the contour of an outer peripheral surface section of the rotor core formed with said two adjacent permanent magnetic pole sections and said magnetic salient pole section interposed therebetween is configured so as to have symmetrical shapes about the salient pole section virtual center lines CL1 or CL2 and so that the contour of the outer peripheral surface sections corresponding to the angle of $360^\circ / p$ about the center of the shaft of the rotor each may be formed into an identical shape, thus resulting in the rotor core having p identical shapes in the outer periphery thereof.

4. The interior permanent magnet synchronous motor as defined in claim 2,

wherein each of the magnetic pole surfaces of said permanent magnet magnetic pole sections is formed into arcuate or elliptic configuration;

wherein each of said magnetic pole surfaces of said permanent magnet magnetic pole sections of rotor core and each of magnetic pole surfaces of said magnetic pole sections of said stator core are arranged so as to have a gap defined therebetween and having a dimension δd which satisfies or almost satisfies the following expression:

$$\delta d = \delta d_0 / \cos[p(\theta_m - \theta_{dm})]$$

wherein δd_0 is the minimum value of the dimension of said gap,

θ_m is an angle defined from a virtual center line CL3 which extends from the center of the shaft through a center of the two salient pole section virtual center lines CL1, CL2 toward the side of the magnetic salient pole section having the open angle α_1 , and θ_{dm} is an angle between the virtual line PL3 which extends from the center of the shaft and through a position where the dimension of the gap has the minimum value and the virtual center line CL3.

5. The interior permanent magnet synchronous motor as defined in claim 4, wherein the following expressions are satisfied while ϕ_1 is an angle defined between the virtual center line CL3 and a virtual line PL1 which is one of the two virtual lines PL1 and PL2 which extend from the center of the shaft through both ends of each of the magnetic pole sections, the virtual line PL1 being positioned on the side of the magnetic salient pole section having the open angle α_2 , and ϕ_2 is an angle defined between the virtual center line CL3 and the virtual line PL2 which is the other of the two virtual lines PL1 and PL2 and which is positioned on the side of the magnetic salient pole section having the open angle α_1 :

$$\phi_2 > \phi_1$$

$$\phi_2 - \phi_1 \approx 0.5 (2m-1) \tau_s (180^\circ / p)$$

$$\phi_2 + \phi_1 \approx u \cdot \tau_s$$

$$\alpha_1 + \alpha_2 \leq (360^\circ / p) - 2(\phi_2 + \phi_1)$$

wherein p is the number of pole pairs and m and u are arbitrary natural numbers.

6. The interior permanent magnet synchronous motor as defined in claim 5, wherein said α_1 , α_2 , ϕ_1 and ϕ_2 are set at such values as to satisfy the following expressions also:

$$(180^\circ / 2p) + (\alpha_1 / 2) - \phi_2 \approx (1/4)(2v_1 - 1) \tau_s$$

$$(180^\circ / 2p) + (\alpha_2 / 2) - \phi_1 \approx (1/4)(2v_2 - 1) \tau_s$$

wherein v1 and v2 are arbitrary natural numbers.

7. The interior permanent magnet synchronous motor as defined in claim 1, wherein said rotor core having a first and a second non-magnetic sections at both ends in the peripheral direction of the magnets, the first and second non-magnetic sections being formed of recesses;

said first non-magnetic section being arranged on the side of the magnetic salient pole section having the open angle α_1 and said second non-magnetic section being arranged on the side of the magnetic salient pole section having the open angle α_2 ;

wherein the shape of said first and second non-magnetic sections are determined that an area of the cross section of the second non-magnetic section is larger than an area of the cross section of said first non-magnetic section.

8. An interior permanent magnet synchronous motor comprising:

- a stator including a stator core provided with a plurality of magnetic pole sections having windings of three phases wound thereon;
- a rotor having four pole pairs
- said rotor including a shaft and a rotor core fixed on said shaft;
- said rotor core having eight permanent magnets incorporated therein in a manner to be spaced from each other at intervals in a peripheral direction thereof;
- said eight permanent magnets each constituting eight permanent magnet magnetic pole sections formed on an outer periphery of said rotor core;
- said rotor being formed with eight magnetic silent pole sections so as to interpose said permanent magnet magnetic pole section therebetween;
- said eight permanent magnet magnetic pole sections consisting of a first and a second groups of permanent magnet magnetic pole sections;
- said first group consisting of four permanent magnet magnetic pole sections arranged to be spaced at equal intervals in the peripheral direction interposing one permanent magnet magnetic pole section of said second group between each adjacent two permanent magnet magnetic pole sections of the first group;
- said second group consisting of four permanent magnet magnetic pole sections arranged to be spaced at equal intervals in the peripheral direction interposing one permanent magnet magnetic pole section of said first group between each adjacent two permanent magnet magnetic pole sections of the second group;
- said eight magnetic salient pole sections consisting of a first and a second groups of the magnetic salient pole sections;
- said first group of magnetic salient pole sections consisting of four magnetic salient pole sections arranged to be spaced at equal intervals in the peripheral

direction interposing one magnetic salient pole section of said second group between each adjacent two magnetic salient pole sections of said first group;

said second group of magnetic salient pole sections consisting of four magnetic salient pole sections arranged to be spaced at equal intervals in the peripheral direction interposing one magnetic salient pole section of said first group between each adjacent two magnetic salient pole sections of said second group ;

wherein the open angle $\alpha 1$ of the four magnetic salient pole sections of said first group is smaller than the open angle $\alpha 2$ of the four magnetic salient pole sections of said second group;

wherein said open angle $\alpha 2$ is determined within the range of $12.9^{\circ} \leq \alpha 2 \leq 17.1^{\circ}$ and said open angle $\alpha 1$ is determined within the range of $5.4^{\circ} \leq \alpha 1 \leq 9.6^{\circ}$, when the slot pitch of said stator core is 7.5° and the slot opening is 2.1° .

9. The interior permanent magnet synchronous motor as defined in claim 8, wherein the shapes of said eight permanent magnet magnetic pole sections and said eight magnetic salient pole sections are determined so that the contour of an outer peripheral surface section of the rotor core formed with two said adjacent permanent magnetic pole sections and said magnetic salient pole section interposed therebetween is configured so as to have symmetrical shapes about the salient pole section virtual center line of CL1 or CL2 and yet so that the contour of the outer peripheral surface sections of said rotor core corresponding to the angle of 90° about the center of the shaft of the rotor each may be formed into an identical shape, thus resulting in the rotor core having four identical shapes in the outer periphery thereof.

10. The interior permanent magnet synchronous motor as defined in claim 9, wherein $\phi 1$ is an angle defined between the virtual center line CL3 and a virtual line PL1, which is one of the two virtual lines PL1 and PL2 which extend from the center of the shaft through both ends of each of the magnetic pole sections, the virtual line PL1 being positioned on the side of the magnetic salient pole section having an open angle $\alpha 2$, and $\phi 1$ is set within the range of $11.025^\circ \leq \phi 1 \leq 15.225^\circ$, and $\phi 2$ is an angle defined between the virtual center line CL3 and the virtual line PL2, which is the other of the two virtual lines PL1 and PL2, the virtual line PL2 being positioned on the side of the magnetic salient pole section having an open angle $\alpha 1$, and $\phi 2$ is set within the range of $14.775^\circ \leq \phi 2 \leq 18.975^\circ$

said open angles $\phi 1$ and $\phi 2$ are determined to satisfy the following expression:

$$1.65^\circ \leq \phi 2 - \phi 1 \leq 5.85^\circ \quad \text{and}$$

$$27.9^\circ \leq \phi 2 + \phi 1 \leq 32.1^\circ$$

11. The interior permanent magnet synchronous motor as defined in claim 10, wherein magnetic pole surface of said permanent magnet magnetic pole sections are formed into arcuate or elliptic shape,

each of said magnetic pole surfaces of said permanent magnet magnetic pole sections of rotor core and each of magnetic pole surfaces of said magnetic pole sections of said stator core being arranged so as to have a gap defined therebetween and having a dimension δd which satisfies the following expression:

$$\delta d = \delta d_0 / \cos[p(\theta m - \theta dm)] \cdots (2)$$

wherein δd_0 is the minimum value of the dimension of the gap,

θm is an angle defined from a virtual center line CL3 which extends from the center

of the shaft through a center of the two salient pole section virtual center lines CL1 and CL2 toward the side of the magnetic salient pole section having an open angle $\alpha 1$;

wherein θ_{dm} is an angle within the range of $1.25^{\circ} \leq \theta_{dm} \leq 3.75^{\circ}$.

12. The interior permanent magnet synchronous motor as defined in claim 2, wherein said rotor core having a first and a second non-magnetic sections at both ends in the peripheral direction of the magnets, the first and second non-magnetic sections being formed of recesses;

said first non-magnetic section being arranged on the side of the magnetic salient pole section having the open angle $\alpha 1$ and said second non-magnetic section being arranged on the side of the magnetic salient pole section having the open angle $\alpha 2$;

wherein the shape of said first and second non-magnetic sections are determined that an area of the cross section of the second non-magnetic section is larger than an area of the cross section of said first non-magnetic section.

13. The interior permanent magnet synchronous motor as defined in claim 3, wherein said rotor core having a first and a second non-magnetic sections at both ends in the peripheral direction of the magnets, the first and second non-magnetic sections being formed of recesses;

said first non-magnetic section being arranged on the side of the magnetic salient pole section having the open angle $\alpha 1$ and said second non-magnetic section being arranged on the side of the magnetic salient pole section having the

open angle $\alpha 2$;

wherein the shape of said first and second non-magnetic sections are determined that an area of the cross section of the second non-magnetic section is larger than an area of the cross section of said first non-magnetic section.

14. The interior permanent magnet synchronous motor as defined in claim 4, wherein said rotor core having a first and a second non-magnetic sections at both ends in the peripheral direction of the magnets, the first and second non-magnetic sections being formed of recesses;

said first non-magnetic section being arranged on the side of the magnetic salient pole section having the open angle $\alpha 1$ and said second non-magnetic section being arranged on the side of the magnetic salient pole section having the open angle $\alpha 2$;

wherein the shape of said first and second non-magnetic sections are determined that an area of the cross section of the second non-magnetic section is larger than an area of the cross section of said first non-magnetic section.

15. The interior permanent magnet synchronous motor as defined in claim 5, wherein said rotor core having a first and a second non-magnetic sections at both ends in the peripheral direction of the magnets, the first and second non-magnetic sections being formed of recesses;

said first non-magnetic section being arranged on the side of the magnetic salient pole section having the open angle $\alpha 1$ and said second non-magnetic section being arranged on the side of the magnetic salient pole section having the open angle $\alpha 2$;

wherein the shape of said first and second non-magnetic sections are determined that an area of the cross section of the second non-magnetic section is larger than an area of the cross section of said first non-magnetic section.

16. The interior permanent magnet synchronous motor as defined in claim 6, wherein said rotor core having a first and a second non-magnetic sections at both ends in the peripheral direction of the magnets, the first and second non-magnetic sections being formed of recesses;

said first non-magnetic section being arranged on the side of the magnetic salient pole section having the open angle $\alpha 1$ and said second non-magnetic section being arranged on the side of the magnetic salient pole section having the open angle $\alpha 2$;

wherein the shape of said first and second non-magnetic sections are determined that an area of the cross section of the second non-magnetic section is larger than an area of the cross section of said first non-magnetic section.